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PATENT APPLICATION

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Atty./Agent Docket No.: CM00914S

Mailing Date: 9-27-00

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Assistant Commissioner for Patents
Box Patent Application
Washington, D.C. 20231

Dear Sir:

Transmitted herewith for filing under 37 CFR 1.53 (b) is a Nonprovisional Utility Patent Application:

__X__ New Application; or

____Continuation; or _______Divisional, or _______ Continuation-in-Part (CIP) Application of prior US application No.________, filed on ________, having US Examiner _________, in Group Art Unit______ ___: of

Inventor(s): Shraga, Boaz Or et al.

For (Title): ECHO SUPPRESSION AND ECHO CANCELLATION

This transmittal letter has 2 total pages.

Enclosed are:

__X__ 3 sheets of formal drawings, along with 39 pages of specification, claims, and abstract.

__X__ Oath or Declaration Combined with Power of Attorney (3 pages)
- __X__ Newly Executed (original or copy)
- _______ Copy from a prior application (if this is a Continuation/Division with no new matter)
  - ____Statement deleting named inventor(s) in prior application if this is a Continuation/Division (See 37 CFR 1.63(d)(2) and 1.33(b).)
  - ____Consider as the above Statement, Please delete as inventors for this application the following inventors named in the prior application: ____________________

__X__ Foreign priority to Great Britain Patent application having serial number 9926731.2 and a filing date of November 11, 1999 is hereby claimed under 35 USC 119.
- __X__ A copy of the priority document is included herewith.

__X__ An Assignment Transmittal Letter and Assignment of the invention to MOTOROLA, INC.

_____ An Information Disclosure Statement (IDS), with ______ PTO-1449, and ____ citation copies.

_____ Petition For Extension of Time for parent application of the present Continuation/Division/CIP application

__X__ Print EFS Inventor Information Sheet(s).

__X__ Return Receipt Postcard

_____ Preliminary Amendment

_____ Please cancel filed claims _________.

_____ Incorporation by Reference (for Continuation/Division application) The entire disclosure of the prior application, from which a copy of the oath or declaration is supplied, is considered as being part of the disclosure of the accompanying application and is hereby incorporated by reference therein.

_____ Since the present application is based on a prior US application, please amend the specification by adding the following sentence before the first sentence of the specification: "The present application is based on prior US application No. _______, filed on____________, which is hereby incorporated by reference, and priority thereto for common subject matter is hereby claimed."

X The filing fee is calculated as follows:

CLAIMS AS FILED, LESS ANY CANCELED BY AMENDMENT

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MULTIPLE DEPENDENT CLAIMS			$260	= $ 0.00
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X One additional copy of this sheet is enclosed

Please forward all correspondence to:

Customer Number **22917**

By: Val Jean Hillman

Val Jean Hillman
for Applicant(s)
Registration No. 34,841
MOTOROLA, INC.
Phone: (847) 847-576-6735
Fax: (847) 576-0721

"Express Mail" EL034004797US

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Tammy A. Olson
Name of person mailing paper or fee

Tammy A Olson 9-27-00
Signature Date

INVENTOR INFORMATION

Inventor One Given Name:: Boaz Or
Family Name:: Shraga
Postal Address Line One:: 11/6 Mevo Hatichon Street
City:: Ramat-Gan
State or Province:: Israel
Country:: Israel
Postal or Zip Code:: 52376
City of Residence:: Ramat-Gan
State or Province of Residence:: Israel
Country of Residence:: Israel
Citizenship Country:: Israel
Inventor Two Given Name:: Mark
Family Name:: Shahaf
Postal Address Line One:: 5/5 Kakal Avenue
City:: Ashdod
State or Province:: Israel
Country:: Israel
Postal or Zip Code:: 77462
City of Residence:: Ashdod
State or Province of Residence:: Israel
Country of Residence:: Israel
Citizenship Country:: Israel
Given Name of Applicant:: Izak
Family Name:: Avayu
Postal Address Line One:: 62 Hacalanit Street
City:: Mevaseret Zion
State or Province:: Israel
Country:: Israel
City of Residence:: Mevaseret Zion
State or Province of Residence:: Israel
Country of Residence:: Israel
Citizenship Country:: Israel
Inventor Three Given Name:: Yishay
Family Name:: Ben-Shimol
Postal Address Line One:: 7 Beba Idelson Street
City:: Ashdod
State or Province:: Israel
Country:: Israel
Postal or Zip Code:: 77739
City of Residence:: Ashdod
State or Province of Residence:: Israel
Country of Residence:: Israel
Citizenship Country:: Israel

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Tammy A Olson
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ECHO SUPPRESSION AND ECHO CANCELLATION

FIELD OF THE INVENTION

The present invention relates to methods and systems for processing sound signals in general, and to methods and systems for processing audio signals in the presence of echo conditions, in particular.

BACKGROUND OF THE INVENTION

Echo cancellation and suppression systems and methods therefor are known in the art. A speech transmission oriented system, such as a speech communication system, includes a sound production unit such as a speaker and a sound detection unit such as a microphone. The speaker produces sounds received from a remote source and the microphone detects voice sounds which are provided by the user. It is noted that the microphone also detects sounds from other sources such as noise and sounds, which are produced by the speaker (echo), after traveling through and acoustic path therebetween.

Methods and systems for “emphasizing” the voice portion over the noise and echo are known in the art. The common

approaches use adaptive filtering to derive a replica of an echo-signal, which is further subtracted from the microphone signal. As a result, a level of the echo-signal is decreased significantly. Speech communication systems, especially hand-held devices, are limited in their processing and storage resources. This fact forces developers to search for new approaches for robust and high quality echo cancellation and echo suppression methods, which can function within these limited conditions.

In the article by A. Hirano et al. "A noise-robust stochastic gradient algorithm with an adaptive step-size suitable for mobile hands-free telephones", Proc. ICASST-95, v.5, pp. 1392-1395, 1995, an adaptive step-size algorithm is proposed. The algorithm controls the step size of the standard NLMS method, based on the reference input signal power and the noise power.

US Patent No 5,608,804 to Hirano, entitled "Method of and apparatus for identifying a system with adaptive filter" is directed to a method of and an apparatus for estimating characteristics of an unknown system, using an adaptive filter, in an echo canceller. A gradient step size, which is controlled dynamically, is a function of the power of the reference input signal. The gradient step size monotonously increases if the power of the reference input signal is

smaller than a threshold and monotonously decreases if the power of the reference input signal is greater than the threshold.

US Patent No 5,546,459 to Sih, et al., entitled "Variable block size adaptation algorithm for noise-robust acoustic echo cancellation" is directed to an apparatus for acoustic echo cancellation using an adaptive filter. The apparatus updates coefficients of the adaptive filter using a signal block of length L. The block size is adjusted in response to the instantaneous signal-to-noise ratio.

SUMMARY OF THE PRESENT INVENTION

It is an object of the present invention to provide a novel method and system for echo suppression, which alleviates the disadvantages of the prior art.

It is another object of the present invention to provide a novel method and system for echo canceling, which alleviates the disadvantages of the prior art.

In accordance with the present invention, there is thus provided an echo canceling apparatus, including a signal processor, an adaptation control unit, connected to the signal processor, an adaptive filter, connected to the signal processor and to the adaptation control unit, and a subtractor, connected to the signal processor, to the adaptation control unit and to the adaptive filter.

The signal processor determines an Euclidean norm of an echo-replica signal. The signal processor also determines an Euclidean norm of an input signal. The echo replica signal can be produced by processing a reference far-end signal with the adaptive filter. The adaptation control unit corrects the coefficients of the adaptive filter. The adaptive filter derives an updated echo-replica signal. The subtractor subtracts the updated echo-replica signal from the input signal and derives an updated error signal thereof.

The echo canceling apparatus can further include a digital-to-analog converter, connected to the signal processor, to the subtractor and to a source of the input signal such as a microphone. The analog-to-digital converter converts an analog input signal into a digital input signal.

In accordance with another aspect of the present invention, there is thus provided a echo canceling method, including the steps of; determining an Euclidean norm of an echo-replica signal, determining an Euclidean norm of an input signal, determining a gradient step size, correcting the coefficients of an adaptive filter, deriving an updated echo-replica signal, and determining an updated error signal by subtracting the updated echo-replica signal from the input signal. The echo replica signal can be produced by processing a reference far-end signal with an adaptive filter.

The input signal can include at least one of the list consisting of an echo-signal, a near-end speech signal, a noise signal and the like. The gradient step size can be a function of the Euclidean norms of the echo-replica and the input signals. According to one aspect of the invention, the value of the function decreases when the values of the near-end speech and noise signals increase,

and the value of the function increases when the values of the near-end speech and noise signals decrease.

The correction of the coefficients of the adaptive filter can be performed by employing the gradient step size, the reference far-end signal and an error signal. According to a preferred embodiment of the present invention, the error signal can be determined at the previous adaptation step.

In accordance with a further aspect of the present invention, there is thus provided an echo suppression apparatus including a first amplitude estimation unit, a second amplitude estimation unit, a comparison unit, connected to the first amplitude estimation unit and to the second amplitude estimation unit, and a decision logic unit connected to the comparison unit.

The first amplitude estimation unit estimates an amplitude measure of a reference far-end signal. The second amplitude estimation unit estimates an amplitude measure of an error signal. The comparison unit compares between the values of the amplitude measure of the far-end signal and the amplitude measure of the error signal and produces a comparison result thereof.

The decision logic unit analyzes the comparison result and produces a control signal thereof. The error signal can be an output

of an echo cancellation system, which is connected to the echo suppression apparatus. The far-end signal and the error signal are generally digital signal blocks, each containing at least one digital sample.

In accordance with yet a further aspect of the present invention, there is thus provided an echo suppression method, including the steps of; estimating an amplitude measure of a reference far-end signal, estimating an amplitude measure of an error signal, comparing between the values of the amplitude measures of the far-end and the error signals, thereby producing a comparison value, and analyzing the comparison value, thereby producing a control signal. The error signal can be received from an echo cancellation system.

The far-end signal and the error signal, are generally digital signal blocks, where each of the digital signal blocks contains at least one digital sample.

In accordance with another aspect of the present invention, there is thus provided an echo suppression apparatus, including a first amplitude estimation unit, a second amplitude estimation unit, a comparison unit, connected to the first amplitude estimation unit and to the second amplitude estimation unit, a delay

unit, connected to the comparison unit, and a decision logic unit connected to the delay unit.

The first amplitude estimation unit produces at least two far-end signal amplitude measure values by estimating an amplitude measure of a reference far-end signal. The reference far-end signal is a sequence of at least two digital signal blocks, where each of the digital signal blocks contains at least one digital sample. The second amplitude estimation unit produces at least two error signal amplitude measure values by estimating an amplitude measure of an error signal. The error signal is a sequence of at least two digital signal blocks, where each of the digital signal blocks contains at least one digital sample.

The comparison unit determines a plurality of value pairs. Each of the pairs includes a selected one of the error signal amplitude measure values and a respective one of the far-end signal amplitude measure values. The comparison unit further compares between the far-end signal amplitude measure value and the error signal measure value, within each of the value pairs and produces at least two comparison results thereof.

The delay unit stores the comparison results. The decision logic unit analyzes the comparison results and produces a control signal thereof.

In accordance with yet another aspect of the present invention, there is provided an echo suppression method including the steps of:

- ξ Producing at least two far-end signal amplitude measure values by estimating an amplitude measure of a reference far-end signal. The reference far-end signal is a sequence of at least two digital signal blocks. Each of the digital signal blocks contains at least one digital sample.
- ξ Producing at least two error signal amplitude measure values by estimating an amplitude measure of an error signal. The error signal includes a sequence of at least two digital signal blocks. Each of the digital signal blocks contains at least one digital sample.
- ξ Determining a plurality of value pairs, where each pair includes a selected one of the error signal amplitude measure values and a respective one of the far-end signal amplitude measure values.

- ξ Comparing between the far-end signal amplitude measure value and the error signal amplitude measure value, within each of the value pairs, thereby producing at least two comparison results.
- ξ Analyzing the at least two comparison results, thereby producing a control signal.

In accordance with another aspect of the present invention, there is thus provided an echo suppression apparatus which includes a first amplitude estimation unit, a second amplitude estimation unit, a comparison unit, connected to the first amplitude estimation unit and to the second amplitude estimation unit, and a decision logic unit, connected to the comparison unit.

The first amplitude estimation unit estimates an amplitude measure of a reference far-end signal. The second amplitude estimation unit estimates an amplitude measure of an error signal. The comparison unit compares between the values of the amplitude measure of the far-end signal and the amplitude measure of the error signal and produces a comparison result thereof.

The decision logic unit analyzes the comparison result and produces a control signal thereof. The error signal can be the output

of an echo cancellation system, which is connected to the echo suppression apparatus of the invention.

In accordance with a further aspect of the invention, there is provided an echo suppression apparatus, including a first amplitude estimation unit, a second amplitude estimation unit, a comparison unit, connected to the first amplitude estimation unit and to the second amplitude estimation unit, a delay unit, connected to the comparison unit, and a decision logic unit connected to the delay unit. The first amplitude estimation unit produces at least two far-end signal amplitude measure values by estimating an amplitude measure of a reference far-end signal, wherein the reference far-end signal is a sequence of at least two digital signal blocks. Each of the digital signal blocks contains at least one digital sample.

The second amplitude estimation unit produces at least two error signal amplitude measure values by estimating an amplitude measure of an error signal, wherein the error signal is a sequence of at least two digital signal blocks. Each of the digital signal blocks contains at least one digital sample.

The comparison unit determines a plurality of value pairs. Each of the pairs includes a selected one of the error signal amplitude measure values and a respective one of the far-end signal

amplitude measure values. The comparison unit compares between the far-end signal amplitude measure value and the error signal measure value, within each of the value pairs and produces at least two comparison results thereof. The delay unit stores the at least two comparison results. The decision logic unit analyzes the comparison results and produces a control signal thereof.

BRIEF DESCRIPTION OF THE DRAWINGS

The present invention will be understood and appreciated more fully from the following detailed description taken in conjunction with the drawings in which:

Figure 1 is a schematic illustration of a speech communication system, constructed and operative in accordance with a preferred embodiment of the present invention;

Figure 2 is a schematic illustration in detail of the echo-cancellation system of Figure 1, constructed and operative in accordance with a further preferred embodiment of the present invention;

Figure 3 is a schematic illustration of a method for operating the echo-cancellation system of Figure 2, operative in accordance with a further preferred embodiment of the present invention;

Figure 4 is a schematic illustration in detail of the echo-suppression system of Figure 1, constructed and operative in accordance with a further preferred embodiment of the present invention; and

Figure 5 is a schematic illustration of a method for operating the echo-suppression system of Figure 4, operative in

accordance with another preferred embodiment of the present invention.

DETAILED DESCRIPTION OF PREFERRED EMBODIMENTS

The present invention alleviates the disadvantages of the prior art by providing better robustness of echo cancellation, whenever an additive background noise and/or near-end speech are present. It also provides a more accurate and computation-effective method of echo suppression.

Reference is now made to Figure 1, which is a schematic illustration of a speech communication system, generally referenced 10, constructed and operative in accordance with a preferred embodiment of the present invention.

Speech communication system 10 includes a receiver 12, a loudspeaker 14, a switch 16, an echo-cancellation system 18, a transmitter 20, an echo-suppression system 22, a comfort noise generator 24, a digital-to-analog converter (D/A) 36 and a microphone 26.

Echo-cancellation system 18 is connected to receiver 12, to digital-to-analog converter 36, to echo-suppression system 22, and to microphone 26. Echo-suppression system 22 is connected to D/A 36, and to switch 16. Transmitter 20 and comfort noise generator 24 are connected to switch 16. Loudspeaker 14 is connected to D/A 36.

Receiver 12 receives an RF signal, extracts the audio information embedded therein and produces a digital audio stream X_k. Receiver 12 further provides the digital audio stream X_k to D/A 36, to echo-suppression system 22 and to echo-cancellation system 18. D/A 36 converts the digital audio stream X_k into an analog signal *x(t)* and provides it to loudspeaker 14. Loudspeaker 14 converts further the signal *x(t)* into an analog sound signal and provides it to a near-end speaker 30. Microphone 26 detects an echo-signal *y'(t)*, which is a combination of the sound, radiated by loudspeaker 14 and a sound, reflected from a reflector 32. Microphone 26 detects also a speech signal v'(t) from the near-end speaker 30 and a noise signal *n'(t)* from a noise source 28. Microphone 26 converts acoustic signals *y'(t), v'(t),* and *n'(t)* into electric signals *y(t), v(t)* and *n(t)*, respectively. Microphone 26 provides a signal *d(t)*, which is a combination of the signals *y(t), v(t)* and *n(t)* to echo-cancellation system 18.

Echo-cancellation system 18 analyzes the signals X_k and *d(t)*, estimates an echo replica and performs echo cancellation. The echo replica estimation is performed by employing a novel adaptive filtering method, which will be described in detail hereinafter. Echo-

cancellation system 18 provides an output digital signal E_k to echo-suppression system 22.

Echo-suppression system 22 analyzes the signals from the loudspeaker 14 and echo-cancellation system 18. Based on predetermined conditions, echo-suppression system 22 replaces, if necessary, the output signal E_k with an artificial noise signal 34, generated by comfort noise generator 24. Echo-suppression system 22 controls switch 16, which performs the switching between the output signal E_k and the artificial noise signal. Switch 16 provides the output signal to transmitter 20.

Reference is now made to Figure 2, which is a schematic illustration in detail of echo-cancellation system 18 (Figure 1), constructed and operative in accordance with a further preferred embodiment of the present invention.

Echo-cancellation system 18 includes analog-to-digital converter (A/D) 58, an adaptive filter 54, an adaptation control unit 62, a signal processor 60, and a summator 56. Adaptive filter 54 is connected to the first input of summator 56, to signal processor 60, and to adaptation control unit 62. A/D converter 58 is connected to the second input of summator 56, and to signal processor 60.

Adaptation control unit 62 is further connected to the output of summator 56, and to signal processor 60.

A/D converter 58 converts an analog signal *d(t)* into a digital signal D_k. System 18 operates on digital signal blocks of length L, hence the signal D_k is a vector of length L, with components $D_k(0)$, $D_k(1)$ ... $D_k(L-1)$. Index *k* denotes a block number and has values 0, 1, 2,... . The signal *d(t)* is a sum of signals *y(t)*, *v(t)* and *n(t)*. Hence, signal D_k will be a sum of respective digital signals Y_k, V_k and N_k, each of them being a vector of length L. Accordingly, the signal X_k is a vector of length L, with components $X_k(0)$, $X_k(1)$ ... $X_k(L-1)$.

Signal processor 60 receives near-end signal D_k and echo-replica signal $\hat{Y}_k$, determines Euclidean norms of the signals D_k and $\hat{Y}_k$, and provides it to adaptation control unit 62. It is noted that the filter tap values, which are used for echo-replica signal $\hat{Y}_k$ calculation, were determined during the previous iteration.

Adaptation control unit 62 receives far-end signal X_k, error (residual) signal $E_k = D_k \quad \hat{Y}_k$ and the Euclidean norms of the signals D_k and $\hat{Y}_k$, and outputs filter tap correction values thereof.

Adaptation control unit 62 provides further corrected filter tap values to adaptive filter 54.

Adaptive filter 54 receives the far-end signal X_k and the corrected filter tap values, and outputs echo-replica signal $\hat{Y}_k$. Adaptive filter 54 provides echo-replica signal $\hat{Y}_k$ to summator 56.

Summator 56 sums signals D_k and $\hat{Y}_k$, produces an error signal E_k at the output, and provides signal E_k to echo-suppression system 22, and to adaptation control unit 62.

Reference is further made to Figure 3, which is a schematic illustration of a method for operating echo-cancellation system 18 (Figure 2), operative in accordance with a further preferred embodiment of the present invention.

In step 70, a far-end signal X_k is received by adaptation control unit 62, and adaptive filter 54. With reference to Figure 2, a digital far-end signal X_k, is provided by a far-end speaker to adaptation control unit 62, and to adaptive filter 54.

In step 72, a near-end signal D_k is received by summator 56, and signal processor 60. With reference to Figure 2, A/D converter 58 converts an analog near-end signal *d(t)* into a digital near-end signal D_k, and provides it to summator 56, and to signal processor 60.

In step 74, Euclidean norms $\|D_k(n)\|$ and $\|Y_k(n)\|$ of the signals D_k and $\hat{Y}_k$ respectively, at time instance n, are calculated. With reference to Figure 2, signal processor 60 receives signals D_k and $\hat{Y}_k$, and determines Euclidean norms $\|D_k(n)\|$ and $\|\hat{Y}_k(n)\|$ according to the following expressions:

$$\|D_k(n)\|^2 \quad \sum_{l\ 0}^{L\ 1} D_k^2(n \quad l), \ \|\hat{Y}_k(n)\|^2 \quad \sum_{l\ 0}^{L\ 1} \hat{Y}_k^2(n \quad l), \qquad (1)$$

Signal processor 60 provides further the Euclidean norms $\|D_k(n)\|$ and $\|Y_k(n)\|$ to adaptation control unit 62.

In step 76, a gradient step size *Π(n),* at time instance n, is determined. With reference to Figure 2, adaptation control unit 62 receives far-end signal block X_k, residual signal block E_k, and the Euclidean norms $\|D_k(n)\|$ and $\|\hat{Y}_k(n)\|$. Gradient step size *Π(n)* is further determined as:

$$\Pi(n) \quad \frac{\Pi_0 \ \|X_k(n)\| \ \Delta \ \|\hat{Y}_k(n)\|^2 \ E}{\|X_k(n)\|^2 \ \Delta \ \|\hat{Y}_k(n)\|^2 \ E \ \left| \|D_k(n)\|^2 \ \ \Delta \ \|\hat{Y}_k(n)\|^2 \right|}, \qquad (2)$$

where Δ and E are constants. The value of Δ depends on hardware and software implementation of the system, and can be determined

experimentally. The optimal value of Δ will be the one which effects in a maximal echo cancellation. The value of E can also be determined experimentally. The constant Δ is dimensionless, and the constant E has dimensions of energy. It is noted, that constants Δ and E can be multi-valued, i.e. they can be represented with vectors, having components $\Delta(i)$, $E(j)$ (i,j = 1, 2, 3,...). The most appropriate values of $\Delta(i)$, $E(j)$ can be selected, depending on the working conditions, and HW and SW implementation. It is appreciated, that other expressions for the gradient step size can be used, such as that proposed in the article by A. Hirano, et al. "A noise-robust stochastic gradient algorithm with an adaptive step-size suitable for mobile hands-free telephones", Proc. ICASST-95, v.5, pp. 1392-1395, 1995.

It is noted, that the value of the gradient step size $\Pi(n)$ is controlled dynamically. It follows from equation (2), that $\Pi(n)$ decreases with a rise in the near-end signal V_k or the noise signal N_k. In other words, the adaptation process will be performed more accurately, and hence, the robustness of the system will improve. In an opposite case of low near-end and noise signals, $\Pi(n)$ will rise, causing, in turn, a rise in adaptation speed.

Based on the gradient step size $\Pi(n)$, adaptation control unit 62 further determines an updated vector $H(n+1)$, at a time $n+1$. The components $H_q(n+1)$ of the vector $H(n+1)$ represent filter tap coefficients and are determined according to the following recurrent expression:

$$H_q(n \quad 1) \quad H_q(n) \quad \Pi(n) \; E_k(n) \; X_k(n \quad q),$$

(3)

where q = 0,1,2,...Q-1, and Q is the order of adaptive filter 54. It is noted that the length L of the signal block X_k, can be less than the order Q of adaptive filter 54. In this case, additional $Q \quad L$ zero valued samples must be appended to the signal block X_k, so that the dimension of the signal block X_k, will be equal to dimension of the adaptive filter 54. Adaptation control unit 62 provides the updated vector H to adaptive filter 54.

In step 80, adaptive filter tap coefficients are updated and an echo-replica signal $\hat{Y}_k$ is derived thereof. With reference to Figure 2, adaptive filter 54 receives near-end signal block X_k, and vector H, and derives the echo-replica signal $\hat{Y}_k(n)$, at a time instance n, according to the following expression:

$$Y_k(n) = \sum_{q=0}^{Q-1} H_k(q)\, X_k(n-q),$$

(4)

The echo-replica signal $\hat{Y}_k(n)$ is further provided to signal processor 60, and to summator 56.

In step 82, signals $\hat{Y}_k(n)$ and $D_k(n)$ are subtracted and an error signal $E_k(n)$ is determined thereof. With reference to Figure 2, summator 56 receives signals $\hat{Y}_k(n)$ and $D_k(n)$ and derives the error signal $E_k(n) = D_k(n) - \hat{Y}_k(n)$ at the output.

In step 84, error signal E_k at time n, is provided to echo-suppression system 22 (Figure 1), and to adaptation control unit 62. With reference to Figure 2, summator 56 provides the error signal E_k at time n, to adaptation control unit 62, for the next iteration, and to echo-suppression system 22.

Reference is now made to Figure 4, which is a schematic illustration in detail of echo-suppression system 22 (Figure 1), constructed and operative in accordance with a further preferred embodiment of the present invention.

Echo-suppression system 22 includes amplitude estimation units 104 and 106, a comparison unit 108, a delay unit 110, and a decision logic unit 112.

Comparison unit 108 is connected to delay unit 110, and to amplitude estimation units 104 and 106. Decision logic unit 112 is connected to delay unit 110.

Amplitude estimation units 104 and 106 receive signals E_k and X_k, respectively. Each of the amplitude estimation units further determines an amplitude estimation $A_E^{(k)}$ and $A_X^{(k)}$ of the respective signals, and provide the result to comparison unit 108.

Comparison unit 108 performs the comparison of amplitude estimations $A_E^{(k)}$ and $A_X^{(k)}$, and provides the result to delay unit 110. Delay unit 110 already contains the results of comparisons made for the previous M-1 pairs of signal blocks. The output of delay unit 110 is a vector $\ni_k$ with components $\ni_k(0)$, $\ni_k(1), \ldots \ni_k(M-1)$. Delay unit 110 provides vector $\ni_k$ to decision logic unit 112.

Decision logic unit 112 analyzes vector $\ni_k$, and produces a control signal P. Decision logic unit 112 provides the control signal P to switch 16 (Figure 1).

Reference is further made to Figure 5, which is a schematic illustration of a method for operating echo-suppression system 22 (Figure 4), operative in accordance with another preferred embodiment of the present invention.

In steps 150 and 152, the far-end signal X_k and error signal E_k are received. With reference to Figure 4, amplitude estimation unit 106 receives the far end signal X_k, and amplitude estimation unit 104 receives error signal E_k from echo-cancellation system 18 (Figure 1).

In step 154, amplitude measures of the far-end and residual signals are estimated. With reference to Figure 4, amplitude estimation units 104 and 106 determine amplitude measures $A_E^{(k)}$ and $A_X^{(k)}$ for signals E_k and X_k, respectively, according to the following expressions

$$A_E^{(k)} = \sum_{l=0}^{L-1} |E_k(l)|, \quad A_X^{(k)} = \sum_{l=0}^{L-1} |X_k(l)|, \qquad (5)$$

where L is a length of signal blocks E_k and X_k. Amplitude measures $A_E^{(k)}$ and $A_X^{(k)}$ are further provided to comparison unit 108.

It is appreciated that instead of amplitude measures $A_E^{(k)}$ and $A_X^{(k)}$, it is possible to use other signal measures, for example energy estimate. It is noted, that in distinction to energy estimation, which is quadratic in signal amplitude, amplitude measures $A_E^{(k)}$ and $A_X^{(k)}$ are linear functions of signal amplitudes E_k and X_k, respectively. The use of $A_E^{(k)}$ and $A_X^{(k)}$ reduces the amount of the required calculations, and furthermore, increases their accuracy. In step 156, amplitude measures $A_E^{(k)}$ and $A_X^{(k)}$ are compared. With reference to

Figure 4, comparison unit 108 receives amplitude measures $A_E^{(k)}$ and $A_X^{(k)}$, compares them, and produces a boolean output $\backepsilon_k(0)$, according to the following conditional expressions:

$$\begin{cases} \backepsilon_k(0) \quad 1, & if \quad A_X^{(k)} \quad A_E^{(k)} \,!\, T \\ \backepsilon_k(0) \quad 0, & otherwise \end{cases}, \qquad (6)$$

where T is a threshold value. The value of T is determined experimentally. The value of $\backepsilon_k(0)$ is further provided to delay unit 110. Delay unit 110 already contains the results of comparisons made for the previous M-1 pairs of signal blocks. The output of delay unit 110 is a vector $\backepsilon_k$ with components $\backepsilon_k(0)$, $\backepsilon_k(1), \ldots \backepsilon_k(M-1)$. Delay unit 110 provides vector $\backepsilon_k$ to decision logic unit 112.

In step 158, the results of the current comparison, and previous *M-1* comparisons of amplitude measures, are analyzed, and a respective control signal is derived thereof. With the reference to Figure 4, decision logic unit 112 receives comparison vector $\backepsilon_k$, analyzes comparison vector $\backepsilon_k$, and derives appropriate control signal *P* for switch 16. The decision process is accomplished in accordance with the following logical scheme:

if $(\backepsilon_k(0)==1,\ \backepsilon_k(1)==1, \ldots \backepsilon_k(M-1)==1)$

count= M

```
endif
count=count-1
if(count>0)
   P==1
else
      P==0
endif
```

In step 160, control signal P is provided to switch 16. With reference to Figure 4, decision logic unit 112 provides control signal P to switch 16. In case $P==1$, switch 16 replaces signal E_k with comfort noise, otherwise signal E_k is provided to transmitter 20.

It will be appreciated by persons skilled in the art that the present invention is not limited to what has been particularly shown and described hereinabove. Rather the scope of the present invention is defined only by the claims, which follow.

CLAIMS

1. An echo canceling method, the method comprising the steps of:

    determining an Euclidean norm of an echo-replica signal;

    determining an Euclidean norm of an input signal;

    determining a gradient step size;

    correcting the coefficients of an adaptive filter;

    deriving an updated echo-replica signal, and

    determining an updated error signal by subtracting said updated echo-replica signal from said input signal.

2. The method according to claim 1, wherein said echo replica signal is produced by processing a reference far-end signal with an adaptive filter.

3. The method according to claim 1, wherein said input signal includes at least one of the list consisting of:

    an echo-signal;

    a near-end speech signal, and

    a noise signal.

4. The method according to claim 1, wherein said gradient step size is a function of said Euclidean norms of said echo-replica and input signals.

5. The method according to claim 4, wherein the value of said function decreases when the values of said near-end speech and noise signals increase, and wherein the value of said function increases when the values of said near-end speech and noise signals decrease.

6. The method according to claim 1, wherein the correction of said coefficients of said adaptive filter is performed by employing said gradient step size, said reference far-end signal and an error signal, said error signal determined at the previous adaptation step.

7. Echo canceling apparatus, comprising:

a signal processor;

an adaptation control unit, connected to said signal processor;

an adaptive filter, connected to said signal processor and to said adaptation control unit, and

a subtractor, connected to said signal processor, to said adaptation control unit and to said adaptive filter.

8. The echo canceling apparatus, according to claim 7, wherein said signal processor determines an Euclidean norm of an echo-replica signal.

9. The echo canceling apparatus, according to claim 7, wherein said signal processor determines an Euclidean norm of an input signal.

10. The echo canceling apparatus, according to claim 8, wherein said echo replica signal is produced by processing a reference far-end signal with said adaptive filter.

11. The echo canceling apparatus, according to claim 9, wherein said input signal includes at least one of the list consisting of:

an echo-signal;

a near-end speech signal, and

a noise signal.

12. The echo canceling apparatus, according to claim 7, wherein said adaptation control unit determines a gradient step size.

13. The echo canceling apparatus, according to claim 12, wherein said gradient step size is a function of said Euclidean norms of said echo-replica and input signals.

14. The echo canceling apparatus, according to claim 13, wherein the value of said function decreases when the values of said near-end speech and noise signals increase and wherein the value of said function increases when the value of said near-end speech and noise signals decrease.

15. The echo canceling apparatus, according to claim 7, wherein said adaptation control unit corrects the coefficients of said adaptive filter.

16. The echo canceling apparatus, according to claim 15, wherein said correction of said coefficients of said adaptive filter is performed by employing said gradient step size, said reference

far-end signal and an error signal, said error signal determined at the previous adaptation step.

17. The echo canceling apparatus, according to claim 7, wherein said adaptive filter derives an updated echo-replica signal.

18. The echo canceling apparatus, according to claim 7, wherein said subtractor subtracts said updated echo-replica signal from said input signal and derives an updated error signal thereof.

19. The echo canceling apparatus, according to claim 7, further comprising a digital-to-analog converter, connected to said signal processor, to said subtractor and to a source of said input signal.

20. The echo canceling apparatus, according to claim 19, wherein said analog-to-digital converter converts an analog input signal into a digital input signal.

21. Echo suppression method comprising the steps of:

estimating an amplitude measure of a reference far-end signal;

estimating an amplitude measure of an error signal;

comparing between the values of said amplitude measures of said far-end and said error signals, thereby producing a comparison value; and

analyzing said comparison value, thereby producing a control signal.

22. The echo suppression method, according to claim 21, wherein said error signal is received from an echo cancellation system.

23. The echo suppression method, according to claim 21, wherein said far-end signal and said error signal, are digital signal blocks, each said digital signal block containing at least one digital sample.

24. An echo suppression method comprising the steps of:

producing at least two far-end signal amplitude measure values by estimating an amplitude measure of a reference far-end signal, wherein said reference far-end signal is a sequence

of at least two digital signal blocks, each said digital signal blocks contains at least one digital sample;

producing at least two error signal amplitude measure values by estimating an amplitude measure of an error signal, wherein said error signal comprises a sequence of at least two digital signal blocks, each said digital signal block contains at least one digital sample;

determining a plurality of value pairs, each said pair including a selected one of said at least two error signal amplitude measure values and a respective one of said at least two far-end signal amplitude measure values;

comparing between said far-end signal amplitude measure value and said error signal amplitude measure value, within each said value pairs, thereby producing at least two comparison results;

analyzing said at least two comparison results, thereby producing a control signal.

25. Echo suppression apparatus comprising:

a first amplitude estimation unit;

a second amplitude estimation unit;

a comparison unit, connected to said first amplitude estimation unit and to said second amplitude estimation unit; and

a decision logic unit connected to said comparison unit.

26. The echo suppression apparatus, according to claim 25, wherein said first amplitude estimation unit estimates an amplitude measure of a reference far-end signal.

27. The echo suppression apparatus, according to claim 25, wherein said second amplitude estimation unit estimates an amplitude measure of an error signal.

28. The echo suppression apparatus, according to claim 25,

wherein said first amplitude estimation unit estimates an amplitude measure of a reference far-end signal,

wherein said second amplitude estimation unit estimates an amplitude measure of an error signal, and

wherein said comparison unit compares between the values of said amplitude measure of said far-end signal and

said amplitude measure of said error signal and produces a comparison result thereof.

29. The echo suppression apparatus, according to claim 28, wherein said decision logic unit analyzes said comparison result and produces a control signal thereof.

30. The echo suppression apparatus, according to claim 27, wherein said error signal is an output of an echo cancellation system.

31. The echo suppression apparatus, according to claim 25,

wherein said first amplitude estimation unit estimates an amplitude measure of a reference far-end signal,

wherein said second amplitude estimation unit estimates an amplitude measure of an error signal, and

wherein said far-end signal and said error signal are digital signal blocks, each said digital signal block contains at least one digital sample.

32. Echo suppression apparatus, comprising:

a first amplitude estimation unit ;

a second amplitude estimation unit;

a comparison unit, connected to said first amplitude estimation unit and to said second amplitude estimation unit;

a delay unit, connected to said comparison unit; and

a decision logic unit, connected to said delay unit.

33. The apparatus for echo suppression, according to claim 32, wherein said first amplitude estimation unit produces at least two far-end signal amplitude measure values by estimating an amplitude measure of a reference far-end signal, wherein said reference far-end signal is a sequence of at least two digital signal blocks, each said digital signal block contains at least one digital sample.

34. The apparatus for echo suppression, according to claim 32, wherein said second amplitude estimation unit produces at least two error signal amplitude measure values by estimating an amplitude measure of an error signal, wherein said error

signal is a sequence of at least two digital signal blocks, each said digital signal block contains at least one digital sample.

35. The apparatus for echo suppression, according to claim 32, wherein said comparison unit determines a plurality of value pairs, each said pair including a selected one of said at least two error signal amplitude measure values and a respective one of said at least two far-end signal amplitude measure values, compares between said far-end signal amplitude measure value and said error signal measure value, within each said value pairs and produces at least two comparison results thereof.

36. The apparatus for echo suppression, according to claim 35, wherein said delay unit stores said at least two comparison results.

37. The apparatus for echo suppression, according to claim 36, wherein said decision logic unit analyzes said at least two comparison results and produces a control signal thereof.

ABSTRACT

Echo canceling method including the steps of determining an Euclidean norm of an echo-replica signal, determining an Euclidean norm of an input signal, determining a gradient step size, correcting the coefficients of an adaptive filter, deriving an updated echo-replica signal, and determining an updated error signal by subtracting the updated echo-replica signal from the input signal.

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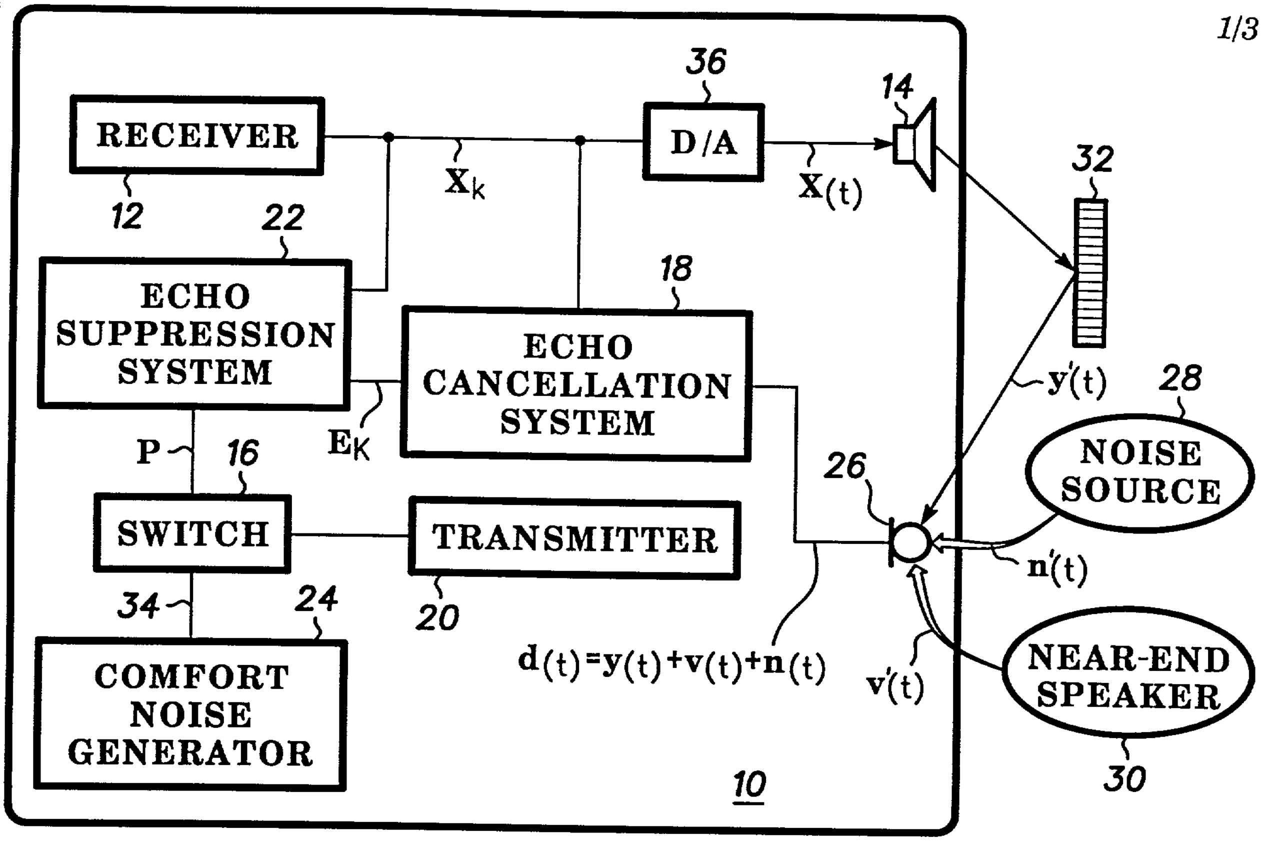
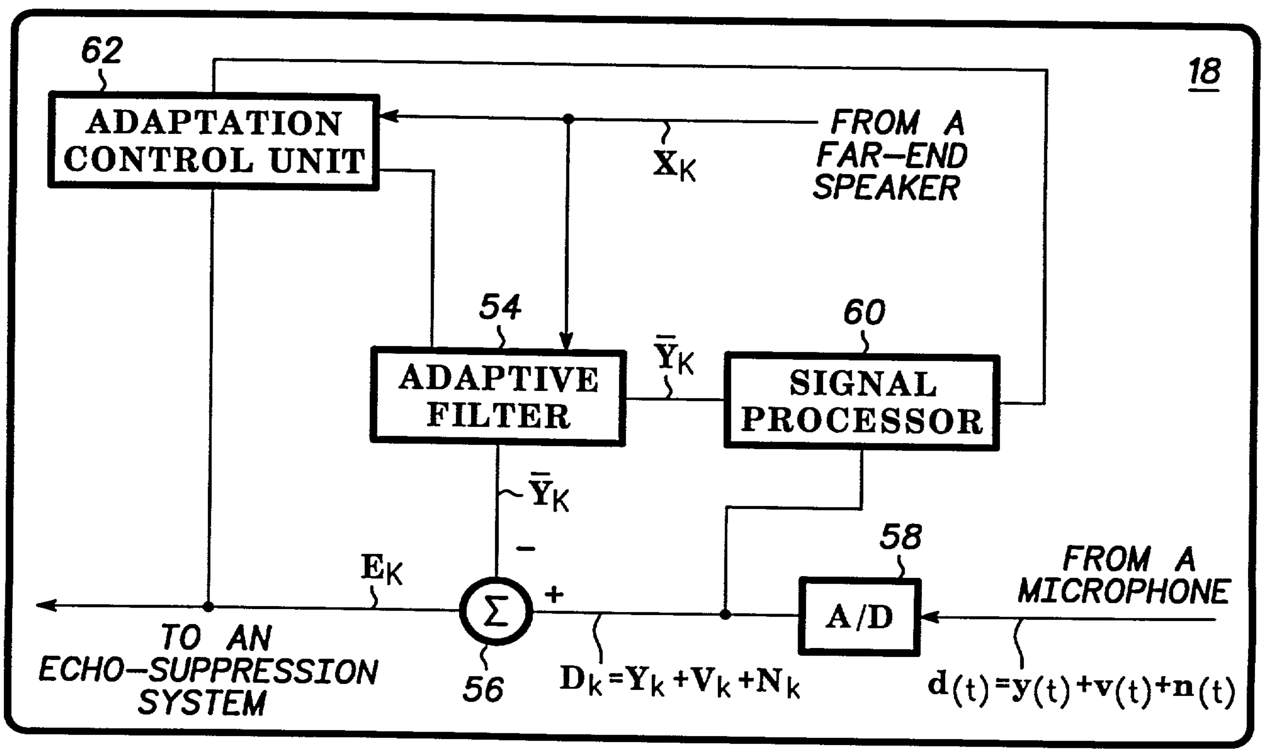


RECEIVER
12
X_k
36
D/A
$X(t)$
14
32
22
ECHO SUPPRESSION SYSTEM
18
ECHO CANCELLATION SYSTEM
E_K
P
16
SWITCH
TRANSMITTER
20
34
24
COMFORT NOISE GENERATOR
$y'(t)$
28
NOISE SOURCE
26
$n'(t)$
$d(t)=y(t)+v(t)+n(t)$
$v'(t)$
NEAR-END SPEAKER
30
10

FIG. 1



62
ADAPTATION CONTROL UNIT
18
X_K
FROM A FAR-END SPEAKER
54
60
ADAPTIVE FILTER
$\bar{Y}_K$
SIGNAL PROCESSOR
$\bar{Y}_K$
58
E_K
–
+
A/D
FROM A MICROPHONE
TO AN ECHO-SUPPRESSION SYSTEM
56
$D_k=Y_k+V_k+N_k$
$d(t)=y(t)+v(t)+n(t)$

FIG. 2

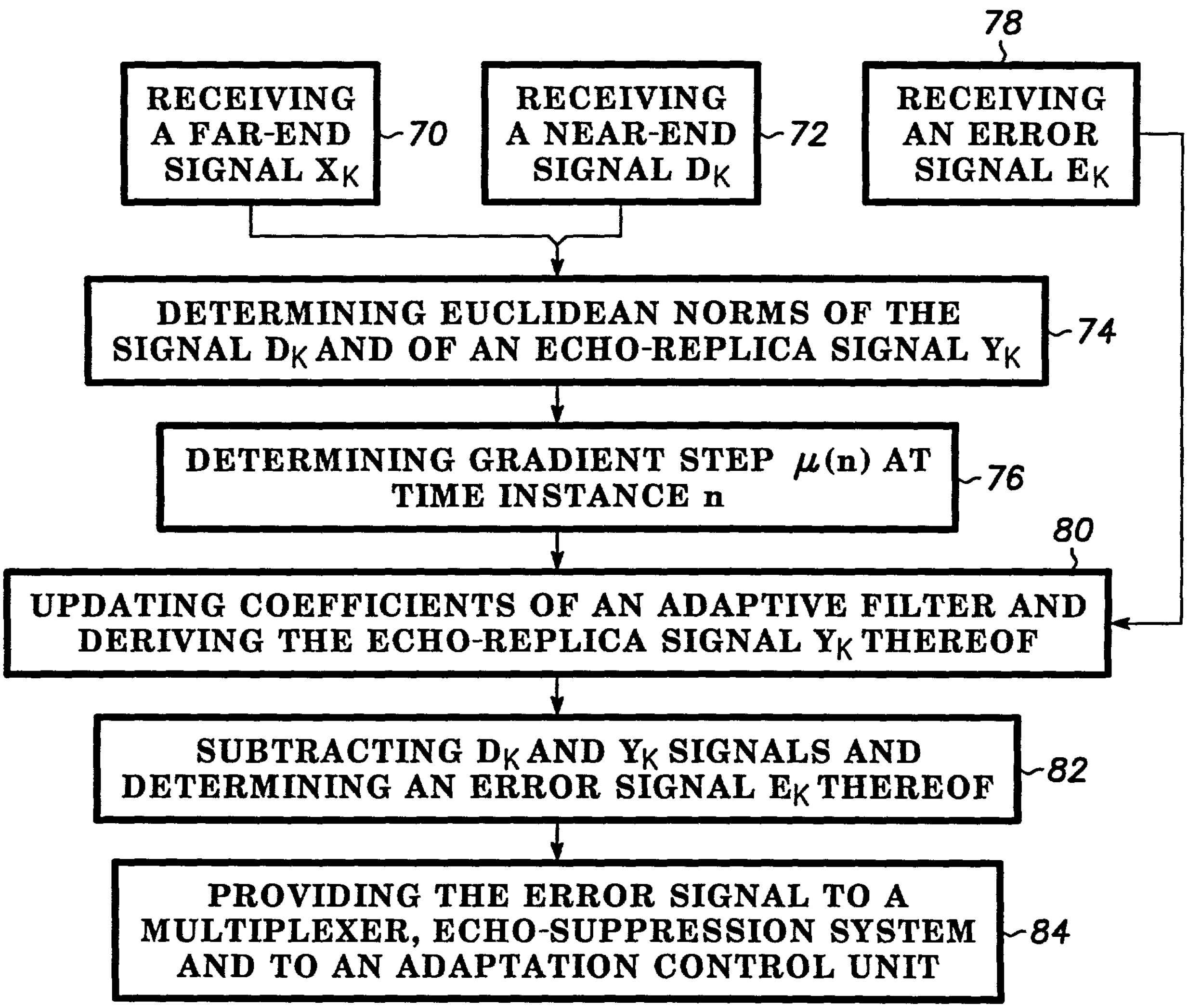
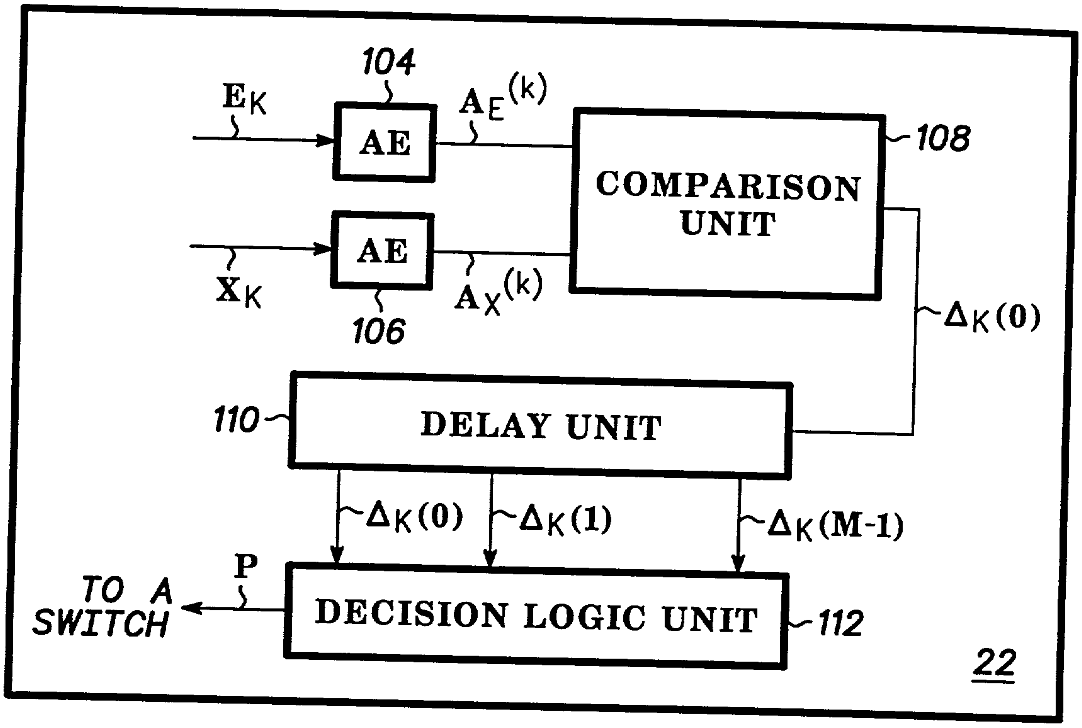
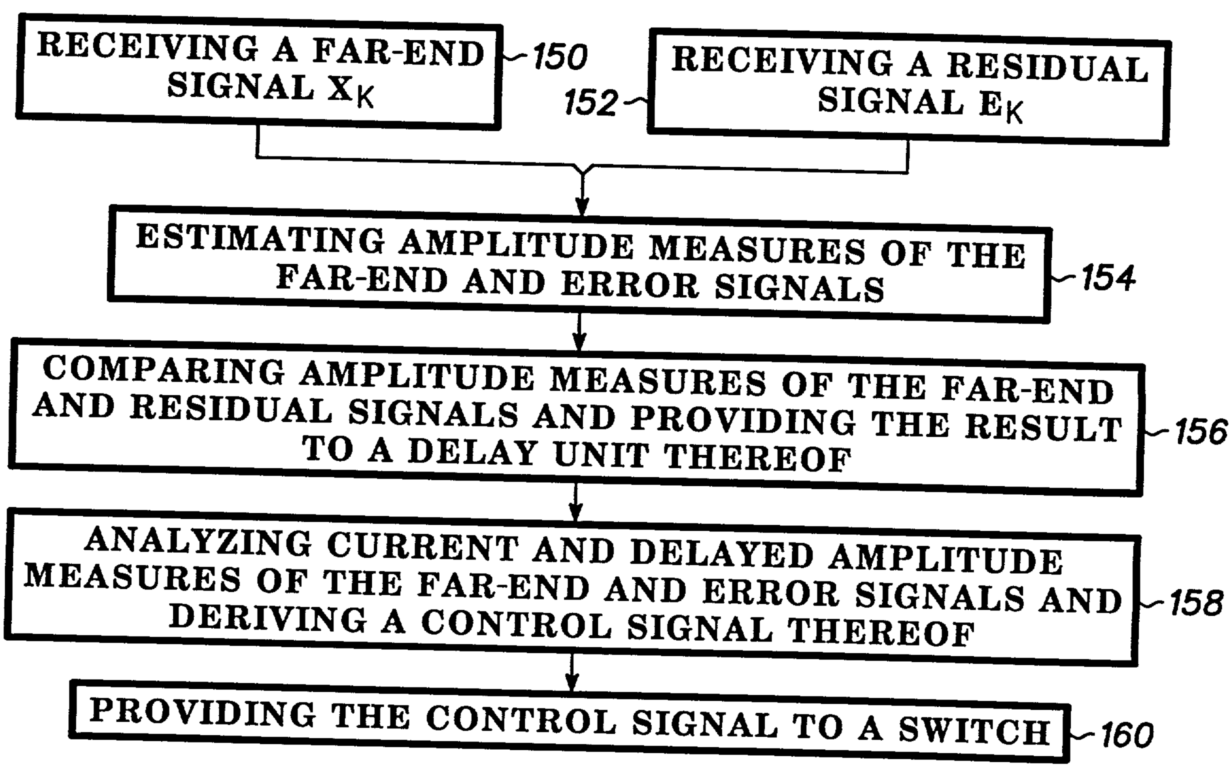

RECEIVING A FAR-END SIGNAL X_K
70
RECEIVING A NEAR-END SIGNAL D_K
72
78
RECEIVING AN ERROR SIGNAL E_K
DETERMINING EUCLIDEAN NORMS OF THE SIGNAL D_K AND OF AN ECHO-REPLICA SIGNAL Y_K
74
DETERMINING GRADIENT STEP $\mu(n)$ AT TIME INSTANCE n
76
80
UPDATING COEFFICIENTS OF AN ADAPTIVE FILTER AND DERIVING THE ECHO-REPLICA SIGNAL Y_K THEREOF
SUBTRACTING D_K AND Y_K SIGNALS AND DETERMINING AN ERROR SIGNAL E_K THEREOF
82
PROVIDING THE ERROR SIGNAL TO A MULTIPLEXER, ECHO-SUPPRESSION SYSTEM AND TO AN ADAPTATION CONTROL UNIT
84

FIG. 3



104
E_K
AE
$A_E(k)$
COMPARISON UNIT
108
AE
X_K
$A_X(k)$
106
$\Delta_K(0)$
110
DELAY UNIT
$\Delta_K(0)$
$\Delta_K(1)$
$\Delta_K(M-1)$
P
TO A SWITCH
DECISION LOGIC UNIT
112
22

FIG. 4



RECEIVING A FAR-END SIGNAL X_K
150
152
RECEIVING A RESIDUAL SIGNAL E_K
ESTIMATING AMPLITUDE MEASURES OF THE FAR-END AND ERROR SIGNALS
154
COMPARING AMPLITUDE MEASURES OF THE FAR-END AND RESIDUAL SIGNALS AND PROVIDING THE RESULT TO A DELAY UNIT THEREOF
156
ANALYZING CURRENT AND DELAYED AMPLITUDE MEASURES OF THE FAR-END AND ERROR SIGNALS AND DERIVING A CONTROL SIGNAL THEREOF
158
PROVIDING THE CONTROL SIGNAL TO A SWITCH
160

FIG. 5

COMBINED DECLARATION AND POWER OF ATTORNEY FOR PATENT APPLICATION

Attorney Docket CM00914S

As a below named inventor, I hereby declare that:

My residence, post office address and citizenship are as stated below next to my name.

I believe I am the original, first and sole inventor (if only one name is listed below), or an original, first and joint inventor (if plural names are listed below), of the subject matter which is claimed and for which a patent is sought on the invention entitled ECHO SUPPRESSION AND ECHO CANCELLATION, the specification of which is attached hereto unless the following box is checked:

☐ Application was filed on ________________
as Application No. ________________
and was amended on ________________.

I hereby state that I have reviewed and understand the contents of the above identified specification, including the claims, as amended by any amendment referred to above.

I acknowledge the duty to disclose information which is material to the examination of this application in accordance with Title 37, Code of Federal Regulations, §1.56.

I hereby claim foreign priority benefits under Title 35, United States Code, § 119(a)-(d) of any foreign application(s) for patent or inventor's certificate listed below and have also identified below any foreign application for patent or inventor's certificate having a filing date before that of the application on which priority is claimed.

Prior Foreign Application(s)			Priority Claimed
9926731.2	GB	11 NOV 99	☑ Yes ☐ No
(Number)	(Country)	(Day/Month/Year Filed)	
			☐ Yes ☐ No
(Number)	(Country)	(Day/Month/Year Filed)	

I hereby claim the benefit under Title 35, United States Code, § 119(e) of any United States provisional application(s) listed below.

(Application Number)	(Filing Date)
(Application Number)	(Filing Date)

I hereby claim the benefit under Title 35, United States Code, § 120 of any United States application(s) listed below and, insofar as the subject matter of each of the claims of this application is not disclosed in the prior United States application in the manner provided by the first paragraph of Title 35, United States Code, § 112, I acknowledge the duty to disclose information which is material to patentability as defined in Title 37, Code of Federal

Regulations, § 1.56 which became available between the filing date of the prior application and the national or PCT international filing date of this application.

(Application Number)	(Filing Date)	(Status - patented, pending, abandoned)
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I hereby appoint the following attorney(s) and/or agent(s) to prosecute this application and to transact all business in the Patent and Trademark Office connected therewith:

Jonathan P. Meyer, Reg. No. 30,477; Doug Fekete, Reg. No. 29,065; K. Cyrus Khosravi, Reg. No. 40,375; Steven G Parmelee, Reg. No. 28,790; J. Ray Wood, Reg. No. 36,062; Daniel K. Nichols, Reg. No. 29,420; Val Jean Hillman, Reg. No. 34,841; Susan L. Lukasik, Reg. No. 35,261; Terri S. Hughes, Reg. No. 41,856; Steven R. Santema, Reg. No. 40,156.

Address all telephone calls to Mr. Jonathan P. Meyer at telephone no. (847) 576 0173.

Address all correspondence to Jonathan P. Meyer, Motorola, Inc., Intellectual Property Section - Law Department, 1303 East Algonquin Road, Schaumburg, IL 60196.

I hereby declare that all statements made herein of my own knowledge are true and that all statements made on information and belief are believed to be true; and further that these statements were made with the knowledge that willful false statements and the like so made are punishable by fine or imprisonment, or both, under Section 1001 of Title 18 of the United States Code and that such willful false statements may jeopardize the validity of the application or any patent issued thereon.

FULL NAME OF FIRST INVENTOR: FIRST MIDDLE LAST	INVENTOR'S SIGNATURE	DATE:
Boaz Or- Shraga		21/12/99
RESIDENCE: 11/6 Mevo Hatichon Str., Ramat-Gan Israel 52376		CITIZENSHIP: Israel
POST OFFICE ADDRESS: Same as above		

FULL NAME OF SECOND INVENTOR: FIRST MIDDLE LAST	INVENTOR'S SIGNATURE	DATE:
Mark Shahaf		Dec 19, 1999
RESIDENCE: 5/5 Kakal Avenue, Ashdod Israel 77462		CITIZENSHIP: Israel
POST OFFICE ADDRESS: Same as above		

FULL NAME OF THIRD INVENTOR: FIRST MIDDLE LAST	INVENTOR'S SIGNATURE	DATE:
Izak, Avayu		21/12/99.

RESIDENCE:	CITIZENSHIP:
62 Hacalanit Str, Mevaseret Zion Israel	Israel
POST OFFICE ADDRESS: Same as above	

FULL NAME OF FOURTH INVENTOR: FIRST MIDDLE LAST	INVENTOR'S SIGNATURE	DATE:
Yishay Ben-Shimol		21.12.99
RESIDENCE: 7 Beba Idelson Str, Ashdod Israel 77739		CITIZENSHIP Israel
POST OFFICE ADDRESS: Same as above		

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